U.S. DEPARTMENT OF THE INTERIOR
U.S. GEOLOGICAL SURVEY

Geologic Map of the Scotts Mills, Silverton, and Stayton Northeast 7.5 Minute Quadrangles, Oregon

By

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Open-file Report 99-141

1999

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INTRODUCTION

The Scotts Mills, Silverton, and Stayton NE 7.5 minute quadrangles are situated along the eastern margin of the Willamette Valley and adjacent lower foothills (Waldo and Silverton Hills) of the Cascade Range (Fig. 1). The terrain within this area is of low to moderate relief, ranging from 100 to more than 1000 ft above sea level. This area is largely rural, with most of the valley floor and low-relief foothills under cultivation. In the last decade, the rural areas outside the boundaries of established towns have experienced significant growth in new homes built and the expansion of housing subdivisions. This growth has placed an increased demand on existing geologic resources (e.g., groundwater, sand and gravel, crushed stone) and the need to better understand potential geologic hazards within this region.

Previous geologic mapping by Piper (1942), Peck and others (1964), Newton (1969), Hampton (1972), Miller and Orr (1984), Orr and Miller (1984), and Miller and Orr (1986, 1988) established and refined the general stratigraphic framework of this region. This mapping identified few faults or folds; earlier investigators were hindered by the lack of reliably identifiable marker horizons within the stratigraphic section. Werner (1991), using available seismic profile lines and well data in the Willamette Valley to locate the top of the Columbia River Basalt Group, was able to identify and map faults within the subsurface. Reconnaissance mapping of the Columbia River Basalt Group (CRBG) units in this region in the early 1980's indicated that these stratigraphic units could serve as a series of unique reference horizons for identifying post-Miocene folding and faulting (Beeson and others, 1985, 1989; Beeson and Tolan, 1990).

The major emphasis of this investigation was to identify and map CRBG units within the Scotts Mills, Silverton, and Stayton NE quadrangles and to utilize this detailed CRBG stratigraphy to identify and characterize structural features.

ACKNOWLEDGMENTS

The authors are very grateful to Karl Wozniak of Oregon Water Resources for providing a tremendous collection of water well logs along with maps containing the accurate locations of the wells. We also want to especially thank Richard Blakely of the U.S. Geological Survey, Menlo

Park, for providing quadrangle-scale aeromagnetic maps to compare to our surface geologic mapping. We also appreciate the landowners for their cooperation in permitting us to access outcrops on their property.

GEOLOGIC SUMMARY

General

The area encompassed by the Scotts Mills, Silverton, and Stayton NE 7.5 minute quadrangles lies along the eastern margin of the Willamette Valley and the adjacent foothills of the Cascade Range (Fig. 1). The Tertiary volcanic and sedimentary bedrock units exposed in the Waldo and Silverton Hills generally dip to the west- northwest into the Willamette Valley where they are covered by a substantial (30 to >150 m-thick) Plio-Pleistocene sedimentary basin fill. The Waldo and Silverton Hills are not a simple dip-slope, but are deformed by a series of northwest- and northeast-trending fault zones that create numerous fault-bounded blocks (horst and grabens). This, coupled with unconformable relationships between the Tertiary volcanic and sedimentary units, creates a much more complex pattern that the topography alone suggests.

Little Butte Volcanics

The oldest unit within the map area is the Oligocene Little Butte Volcanics which is exposed in the northeast portion of the Scotts Mills quadrangle. This unit was originally mapped and described in this area by Harper (1946) as “Molalla Formation and pre-Butte Creek lavas”. In their mapping of the western Cascade Range in Oregon, Peck and others (1964) assigned Harper’s (1946) unit to the “Little Butte Volcanic Series” of Wells (1956). The Little Butte Volcanics represents an early phase of Cascade arc volcanism (Peck and others, 1964; Hammond, 1979, 1989; Priest and others, 1983). The total thickness of this unit is not known within the map area, but is >300 m-thick based upon surface and subsurface data. Hampton (1972, p. 13) suggests that the Little Butte Volcanics may exceed 2100 m in thickness in this region based upon data from a petroleum exploration well (Humble Oil and Refining Company - Wicks Number 1; see Werner, 1991, p. 69) located just off the eastern margin of the Stayton NE quadrangle (sec.11, T7S, R1E).

In the Scotts Mills quadrangle, exposures of the Little Butte Volcanics reveal that it consists dominantly of interbedded basalt, basaltic andesite, and porphyritic andesite flows (Table 1) with very minor amounts of intercalated volcaniclastic and pyroclastic deposits. Little Butte flows appear to have been generally emplaced as a series of relatively narrow, 5-15 m-thick, “shoe-string” pahoehoe and aa flows. Thick flows (>20 m-thick) are much less common. Little Butte flows display a wide range of primary (cooling joint) jointing patterns, ranging from platy columnar to entablature-colonnade. Platy cooling joints can range from horizontal to vertical and impart a “shale-like” appearance to many Little Butte outcrops. No pillow or hyaloclastite complexes were found associated with Little Butte flows in the Scotts Mills quadrangle. No trace of eruptive centers (dikes or vent complexes) for the Little Butte flows in the Scotts Mills quadrangle were found during our investigation. However, the general nature and characteristics of these Little Butte flows suggest that they may have been products of shield and composite volcanoes.

Typically only the blocky and columnar center portions of Little Butte flows are seen in natural exposures. This is because Little Butte vesicular flow-tops and scoriaceous interflow zones (e.g., flow top breccias, flow levees) are weathered and altered and, in some extreme cases, these zones have been completely converted to clay. The original character of these clay “beds” can only be determined from occasionally preserved relic textures. Primary cooling joints within the dense interiors of the flows are typically altered to some extent, displaying reddish to yellow-green colors caused by secondary mineralization.

The age of the Little Butte Volcanics exposed within, or immediately adjacent to, the Scotts Mills quadrangle is poorly constrained. Peck and others (1964, p. 8) assigned an Oligocene to early Miocene age to this unit based on fossil leaf data from a tuff bed locality that lies northeast of the map area. Peck and others (1964) and Hampton (1972) noted that the Little Butte Volcanics interfingers with, and is overlain by, thick sequence of marine sedimentary rocks (Scotts Mills Formation of Miller and Orr (1986, 1988)). Our mapping within the Scotts Mills quadrangle (Garret Creek area - sec. 2 and 45, T6S, R1E), and water well driller’s logs from this same area, also suggest this interfingering relationship. Miller and Orr (1986, 1988) assign a middle Oligocene age to the Scotts Mills Formation (their Marquam Member) in the Garret Creek area, but indicate that the Scotts Mills Formation unconformably overlies the Little Butte Volcanics (Miller and Orr, 1984, 1986, 1988). No isotopic age determinations have been made on Little Butte flows in, or near, the map area. Potentially correlative flows located both east and south of these maps have been dated using K-Ar and 40Ar-39Ar methods (Lux, 1981; Verplanck, 1985) and range from early Oligocene to early Miocene in age.

The exposure of Little Butte Volcanics, and continued presence to the west (>10 km) in the subsurface (Werner, 1991), raises an interesting question as to the reason for their occurrence away from the main eruptive axis of the Oligocene Western Cascade Range. There appears to be an intriguing similarity in the overall distribution patterns of the westward extension of the Little Butte Volcanics and portions of the Plio-Pleistocene Boring Lavas. Boring vents and flows are found along the western margin of the Portland Basin, many tens of kilometers from the main axis of High Cascade volcanism. Faults associated with the northwest-trending Portland Hills-Clackamas River structural zone (Fig. 2) provide a pathway for Boring magmas to migrate away from the axis of High Cascade volcanism. Perhaps the initial development of the northwest-trending faults associated with the Gales Creek-Mount Angel structural zone (Fig. 2) provided similar vertical pathways along which the more fluid Little Butte basaltic and andesitic magmas could migrate outward from the main axis of Western Cascade volcanism.

Scotts Mills Formation

Overlying the Little Butte Volcanics is a thick (>1000 m) sequence Oligocene to Miocene marine inner neritic to terrestrial sediments; these sediments are the oldest exposed rocks on both the Silverton and Stayton NE quadrangles. In previously investigations, these sediments were informally named the Butte Creek beds by Harper (1946) and subsequently called “marine tuff and sandstone” by Peck and others (1964) and “marine rocks” by Hampton (1972). As a result of their mapping and study, Miller and Orr (1986) proposed the name “Scotts Mills Formation” for these sediments and designated the type section as the exposures along Butte Creek, below and above the town of Scotts Mills. Miller and Orr (1986) further subdivided the Scotts Mills Formation into three intercalated, time-transgressive members, the Marquam, Abiqua, and Crooked Finger Members. The extent of these members have been previously mapped for the Scotts Mills (Miller and Orr, 1984) and Stayton NE (Orr and Miller, 1984) quadrangles. The reconnaissance-style maps of Miller and Orr (1984) and Orr and Miller (1984) do not provide enough detailed information for us to adequately differentiate members of the Scotts Mills Formation. Moreover, we neither had the experience or time to reliably sort out these units ourselves. Therefore, we were compelled to map these sediments as undifferentiated Scotts Mills Formation on all three quadrangles.

The Scotts Mills Formation consists of a diverse range of marine sandstones, siltstones, conglomerates, and rare limestones as well as less common fluvial/paludal deposits consisting of conglomerates, sandstones, siltstones, claystones, and coals. Marine sediments range from volcaniclastic to siliciclastic in composition and are locally highly fossiliferous (Miller and Orr, 1986, 1988). Scotts Mills sediments are typically moderately to well indurated, with cementing agents ranging from calcium carbonate to silica. Despite their relative hardness, they tend to develop moderately thick soils and vegetative cover on natural slopes. Within the map area, the best continuous exposures of the Scotts Mills Formation are found in stream bottoms (Scotts Mills quadrangle - Butte Creek, Abiqua Creek; Stayton NE quadrangle- upper Pudding River (sec. 37, T8S, R1W), Drift Creek (sec. 25, T7S, R1W)). Farm roads on Missouri Ridge (Scotts Mills quadrangle secs. 11, 12, 13, T6S, R1E) and the ridge between Abiqua and Alder Creeks (Scotts Mills quadrangle - secs. 34, 35, T6S, R1E) also provide intermittent exposures of this formation. For a complete description of the sedimentology, paleontology, and inferred depositional history of the Scotts Mills Formation see Miller and Orr (1986, 1988).

Miller and Orr (1986, p. 139-141; 1988, p. 959) state that the basal portion of the Scotts Mills Formation unconformably overlies the Little Butte Volcanics, with as much as 100 m of erosional relief developed on the Little Butte surface prior to the deposition of the Scotts Mills Formation. They conclude that the basal portion of the Scotts Mills Formation (their Marquam Member) was deposited during a period of marine transgression into a quiescent ancestral Cascade volcanic arc (Miller and Orr, 1986, p. 143). This conclusion seems to contradict the previously reported interfingering of Little Butte Volcanics and "marine rocks" (Scotts Mills Formation) by Hampton (1972, p. 16-17). Relationships between exposures of Little Butte andesite flows and Scotts Mills sediments in the upper reaches of Garret Creek on the Scotts Mills quadrangle could be interpreted to indicate that these two formations are intercalated or conversely that a series of faults juxtapose these units and simply give the appearance that they are interfingered. Subsurface data obtained from water well driller's logs from this same area indicate that Little Butte flows are interbedded with epiclastic sediments which we infer to be Scotts Mills Formation. This subsurface data compels us to favor an interfingering interpretation between the Little Butte Volcanics and Scotts Mills Formation. These data support Hampton's (1972) conclusion that the "marine rocks" (Scotts Mills Formation) are at least in part interfingered with Little Butte Volcanics and indicate that the Oligocene ancestral Cascade volcanic arc in this area was not magmatically quiescent as Miller and Orr (1986, 1988) suggest.

As defined by Miller and Orr (1986, p. 148-150), the Scotts Mills Formation grades into, and is overlain by, fluvial volcaniclastic and pyroclastic deposits of their Molalla Formation. Their Molalla Formation ranges in age from late Oligocene to early Miocene and also includes younger middle Miocene deposits that interfinger with, and overlie Columbia River Basalt Group flows in this area (Miller and Orr, 1986, Fig 3, p. 141). Minor Molalla Formation deposits had been previously mapped along the southeast edge of both the Stayton NE (Orr and Miller, 1984) and the Scotts Mills (Miller and Orr, 1984) quadrangles. In our mapping of the Scott Mills quadrangle, we found that the deposits previously mapped as Molalla Formation by Miller and Orr (1984) consisted of micaceous, quartzose, arkosic sandstones and fossiliferous siltstones that, by definition, belongs to the Scotts Mills Formation (their Abiqua Member). Our mapping of the Molalla Formation deposits on the Stayton NE quadrangle indicates that they stratigraphically lie above CRBG flows (specifically the basalt of Sand Hollow) and are more properly considered to be Sardine Formation. In our mapping, we encountered no unequivocal exposures of Miller and Orr's (1986) Molalla Formation. However, some water well driller's logs describe sediments that could possible belong to either Miller and Orr's (1986) Molalla Formation or their Crooked Finger Member of the Scotts Mills Formation.

Columbia River Basalt Group (CRBG)

Middle Miocene CRBG lava flows present within the map area represent the distal portions of voluminous continental flood basalt flows that were erupted from linear fissure system located hundreds of kilometers to the northeast in northeastern Oregon and southeastern Washington (Beeson and others, 1985, 1989). More than 300 flood-basalt flows were produced over a 11 million year span of Columbia River basalt volcanism from 17 to 6 Ma (Swanson and others, 1979; Tolan and others, 1989). CRBG flows eventually covered more than 163,000 km^2 in Washington, Oregon, and Idaho (Fig. 2) and have a total estimated volume in excess of 174,000 km^3 (Tolan and others, 1989). While Columbia River basalt eruptive activity spanned an 11 million year period, more than 96 volume-percent of the CRBG was emplaced over a 2.5 million year span from 17 to 14.5 Ma (Tolan and other, 1989; Reidel and others, 1989; Swanson and others, 1979). Flows emplaced during this peak period of eruptive activity were often of extraordinary size, exceeding 1,000 km^3 in volume and covering many tens of thousands of square kilometers (Tolan and other, 1989; Reidel and others, 1989; Reidel and Tolan, 1992).

The relatively great distances that CRBG flows traveled from their vent systems is attributable to a combination of both intrinsic properties (i.e., huge volume and rapid eruption rates) and external paleotopographic and paleoenvironmental factors (Reidel and others, 1994; Beeson and Tolan, 1996; Beeson and others, 1985, 1989). Flow of lava away from the linear fissure systems was directed by regional-scale tectonic features (i.e., Palouse Slope, Pasco Basin, Columbia Trans-Arc Lowland; Fig. 2) and continued regional subsidence (Reidel and others, 1994; Beeson and others, 1989; Reidel and Tolan, 1992) that combined to produce a westward, regional down-gradient pathway. The Columbia Trans-Arc Lowland (Fig. 2) provided voluminous CRBG flows a lowland route across the middle Miocene Cascade Range into western Oregon and Washington (Beeson and others, 1989; Beeson and Tolan, 1990, 1996). Once in western Oregon, the paths of these flows were strongly influenced by major structural features (Fig. 3) and paleoriver canyons of the ancestral Columbia River system (Beeson and others, 1985, 1989; Beeson and Tolan, 1990, 1996).

Significant variations in the lithologic, geochemical, and paleomagnetic properties between CRBG flows has allowed this sequence of flood basalt flows to be subdivided into a host of stratigraphic units (Fig. 4) that can be reliably identified and mapped on a regional basis (Swanson and others, 1979; Reidel and others, 1989; Tolan and others, 1989; Beeson and others, 1985, 1989; Wells and others, 1989). We have employed these criteria to identify and map the CRBG units within the Scotts Mills, Silverton, and Stayton NE quadrangles.

Arrows on Figure 4 denote the CRBG units that are present within the map area. The composite CRBG section for the map area consists of approximately 10 sheet flows; seven flows belonging to members of the Grande Ronde Basalt and 3 flows belonging to units of the

Frenchman Springs Member of the Wanapum Basalt (Fig. 4). The thickness of the CRBG section within the map area varies greatly, ranging from 0 to > 180 m-thick. This variation in thickness reflects the existence of pre-CRBG topography (hills and valleys) within the map area. This paleotopography appears to have been created by deformation along a series of northwest- and northeast-trending fault zones that transect this region. These fault zones produced an irregular pattern of up- and down-faulted blocks (horst and graben structures) within the Little Butte Volcanics and Scotts Mills Formation. The first CRBG sheet flows to enter the map area (Ortley and Umtanum Members, Grande Ronde Basalt; Fig. 4 and 5e, f) were largely confined to these lows and consequently have a rather restricted distribution; subsequent Grande Ronde flows (Winter Water member; Fig. 4 and 5d) eventually inundated these lows thus allowing later CRBG flows to be emplaced over a wider area.

One phenomenon commonly found associated with the earliest CRBG flows (Ortley, Umtanum, and Winter Water members) is the formation of thick flow lobes. We think that the formation of such flow lobes is a response to paleoground conditions that resulted in the rapid extraction heat from the advancing lava (e.g., paleoground surface consisting of wet Scotts Mills sediment). Such conditions would inhibit rapid lava flowage and cause the sheet flow to form energy-conserving tongues that would be inflated as lava tried to advance. Occasionally these early flows would also burrow into (invade) and deform the underlying Scotts Mills sediment. Excellent examples of this phenomenon can be found within the map area.

On the Stayton NE quadrangle in an abandoned quarry (sec. 55, T7S, R1W), a single Winter Water flow invaded older Scotts Mills sandstone creating complex series of flow lobes and discontinuous, contorted sedimentary “interbeds”. The presence of a baked zone along the bottom of the “interbeds” as well as dikelets injected upwards into the “interbeds” makes this a classic example of an invasive CRBG flow. Several additional examples of invasion involving the Winter Water flow can be found on the Scotts Mills quadrangle. The first can be found in a small quarry along Butte Creek Road (SW1/4 sec. 24, T6S, R1E). Here lobes of a Winter Water flow have invaded sandstones and siltstones of the Scotts Mills Formation and display similar features and relationships found in the quarry on the Stayton NE quadrangle. Perhaps the most interesting example of a CRBG flow invading Scotts Mills Formation can be found immediately downstream from the dam on Butte Creek at the town of Scotts Mills. Here the Winter Water flow has invaded Scotts Mills siltstones and sandstones producing many of the same features described above. However here the invading Winter Water lava caused the formation of a small, asymmetrical anticlinal fold within the Scotts Mills sediments.

When present, the Ortley and Umtanum Members can consists of up to four flows and have a collectively thickness that ranges from 10 to > 60 m. The Winter Water member consists of up to two flows and have a collectively thickness that ranges from 5 to >40 m. Ortley, Umtanum, and Winter Water flows appear very similar in outcrop, all generally displaying an entablature/colonnade jointing and only rarely exhibiting an entirely blocky to columnar jointing pattern. All of these flows are very fine-grained to glassy in hand sample; Winter Water flows can be distinguished from older aphyric Ortley and Umtanum flows by the presence of small (<0.3 cm in size) plagioclase glomerocrysts that often display a distinctive radial or spoke-shaped habit. Distribution of plagioclase glomerocrysts within Winter Water flows are often uneven and they tend to be less abundant in the basal portion of the flows. Thin (<0.3 m-thick), discontinuous fluvial volcaniclastic sedimentary interbeds were occasionally found between these older Grande Ronde flows; the only significant sedimentary deposits associated with these flows are found in places were they invaded the older Scotts Mills Formation as noted above. Vesicular flow tops of Ortley, Umtanum, and Winter Water flows typically display only minor evidence of weathering or alteration. No notable pillow/hyaloclastite complexes were found at the base of these flows, despite the fact that they were the earliest CRBG flows to enter this area.

A single Sentinel Bluffs flow (Fig. 4 and 5c) represents the youngest Grande Ronde member within the map area. This Sentinel Bluffs flow has the greatest areal extent of all the Grande Ronde units present within the map area. The greater areal extent of this flow is probably not simply related to its size; data suggest that Winter Water flows were much more voluminous than Sentinel Bluffs flows (Reidel and others, 1989). We think that the greater areal extent of the Sentinel Bluffs flow is largely the result of earlier Grande Ronde flows (Ortley, Umtanum, and Winter Water members) that inundated and leveled the existing paleotopography also created paleoenvironmental conditions that allowed this Sentinel Bluffs flow to spread evenly and more thinly in response to the topography. The single Sentinel Bluffs flow within the map area ranges from 5 to 25 m-thick. This flow typically displays a well developed blocky to columnar jointing style and only exhibits an entablature/colonnade pattern at its flow margins where it onlaps older topography (e.g., Stayton NE quadrangle - Drift Creek quarry on Victor Point Road; and in section 34, T5S, R1E on the Scotts Mills Quadrangle). This flow is medium-grained, occasionally diktytaxitic, and rarely plagioclase phyric with small (<0.5 cm in size) tabular phenocrysts. In the field it can be distinguished from older Grande Ronde flows on the basis of hand sample lithology and stratigraphic position. The Sentinel Bluffs flow also has a distinctive geochemical composition that readily distinguishes it from older Grande Ronde flows and younger Frenchman Springs Member flows found within the map area.

The vesicular flow top of the Sentinel Bluffs flow is often moderately to deeply weathered with the glassy groundmass between vesicles altered to clay. This decomposition often imparts a cream to yellowish white “bleached” appearance to the Sentinel Bluffs flow top and gives it the outward appearance of a sedimentary rock. This relatively severe weathering is the result of a substantially longer period of exposure to subaerial weathering (>200,000 years vs. 10,000 to

30,000 year hiatus between emplacement of older Grande Ronde flows) before being covered by the next CRBG flow (Beeson and others, 1985, 1989; Beeson and Tolan, 1996). This hiatus in CRBG volcanism permitted soils to develop on Sentinel Bluffs flow tops and rivers and streams to reestablish drainage systems across areas inundated by Grande Ronde flows. Within the map area, a thin (0.3 to >3 m-thick) interbed overlies the Sentinel Bluffs flow. This interbed ranges from a paleosol developed on the Sentinel Bluffs flow top to fluvial volcaniclastic and siliciclastic siltstones and sandstones. Springs and seeps are commonly found along this horizon. Interpretation of water well driller's logs suggests that this sedimentary interbed may be much thicker (3 to >20 m-thick) in the Willamette Valley (Silverton quadrangle) than in the Waldo and Silverton Hills to the east.

On the Columbia Plateau, sedimentary deposits found within the stratigraphic interval defined by the top of the Grande Ronde Basalt and the base of the Frenchman Springs Member (Wanapum Basalt) belong to the Vantage Member of the Ellensburg Formation (Swanson and others, 1979). This same stratigraphic interval can be recognized in western Oregon and the term "Vantage interbed" or, lacking the presence of sediments, "Vantage horizon" is often informally employed by CRBG stratigraphers (Beeson and Moran, 1979; Beeson and others, 1985, 1989; Beeson and Tolan, 1990, 1996). In the map area, Miller and Orr (1986) have defined all sediments interfingered with the CRBG as belonging to their Molalla Formation. However sediments found on the "Vantage horizon" within the map area are too discontinuous and thin to depict on the maps as a separate unit; when present, these sediments are included in the overlying Frenchman Springs unit.

The long hiatus in CRBG eruptive activity following the emplacement of the Sentinel Bluffs Member allowed the ancestral Columbia River system to reestablish and new path through western Oregon; this hiatus also allowed significant topographic relief to develop on the Yakima Fold Belt structures within the Columbia Trans-Arc Lowland and on major northwest-trending fault zones in western Oregon (Fig. 3). These features were a significant control over the eventual areal extent of subsequent CRBG flows that advanced into western Oregon and Washington (Beeson and others, 1985, 1989; Beeson and Tolan, 1990, 1996).

The first Frenchman Springs flow to enter western Oregon was the basalt of Ginkgo (Fig. 4). As the Ginkgo flow advanced into the Columbia Trans-Arc Lowland, it encountered the head of the ancestral Columbia River canyon (Fig. 3). The Ginkgo flow used the ancestral Columbia River canyon as a ready-made conduit to the west, but in the process totally overwhelmed and destroyed this course of the ancestral Columbia River (Beeson and others, 1985; Beeson and Tolan, 1996). Ginkgo lava did over top the ancestral Columbia River canyon and spread laterally as a sheet flow (Beeson and Tolan, 1996), but did not reach the map area which lies west and north of this former course of the Columbia River (Fig. 3). The next Frenchman Springs flows, the basalt of Silver Falls (Fig. 4), followed the same generally pathway into western Oregon (Fig. 5b) as the Ginkgo flows. However, the Silver Falls flows were not confined to a deep canyon and were emplaced as sheet flows.

In the map area, the basalt of Silver Falls consists of one or two flows and collectively ranges from 15 to 45 m in thickness. Silver Falls flows are commonly blocky to columnar jointed, with individual columns often exceeding 1 m in diameter. Both flows are typically medium- to coarse-grained, diktytaxitic, and abundantly microphyric with acicular laths of plagioclase that readily standout from the groundmass. The abundantly microphyric texture of the Silver Falls flows is its most characteristic lithologic property (Beeson and others, 1985, 1989). The upper flow is sparsely phyric with plagioclase phenocrysts that range from 0.5 to 3 cm in size. The lower flow is typically abundantly plagioclase phyric with glomerocrysts ranging from 0.5 to >3 cm in size. Silver Falls flows can usually be distinguished in the field from both the older Sentinel Bluffs flow and younger Sand Hollow flow on the basis of stratigraphic position and lithology; chemical composition of the Silver Falls flows is distinct and can be easily distinguished from either Sentinel Bluffs or Sand Hollow flows (Table 1).

The last CRBG unit to enter the map area was a single basalt of Sand Hollow flow (Fig. 4). Up to five Sand Hollow flows reached western Oregon (Fig. 5a), but only a single flow advanced into the map area. Best exposures of this Sand Hollow flow are found on the Stayton NE quadrangle were it underlies much of the Waldo Hills. Here the Sand Hollow flow ranges from 10 to 20 m-thick and displays a entablature/colonnade jointing pattern which is an uncommon jointing style for Frenchman Springs flows. This flow is typically glassy to fine-grained and sparsely plagioclase phyric with glomerocrysts <2 cm in size. In the field it can be readily distinguished from older Silver Falls flows on the combined basis of jointing habit and lithology - specifically the lack of abundant plagioclase microphenocrysts. In hand sample the Sand Hollow flow does bear some resemblance to the Sentinel Bluffs flow, but can be distinguished by the presence of occasional, large, plagioclase phenocrysts. The Sand Hollow flow can also be readily distinguished from other CRBG units in the map area on the basis of it chemical composition (Table 1).

Being the last CRBG flow emplaced within the map area, the Sand Hollow flow was subjected to a long period of subaerial exposure. Consequently this flow is often much more deeply weathered, especially the vesicular flow top and major vertical cooling joints within the entablature/colonnade. This weathering pattern results in the production of the large, subrounded, hackly “boulders” that plague many farm fields on the Stayton NE quadrangle.

A discontinuous interbed, consisting of fluvial volcaniclastic siltstones/sandstones or poorly developed paleosols, is present at the contact between the Silver Falls and Sand Hollow flows in the map area. When present, the interbed is typically < 3 m-thick and is not mapped as a separate unit due to its sporadic occurrence and thinness. Numerous springs and seeps emanate from the Sand Hollow/Silver Falls contact.

Sardine Formation

In the map area, the middle Miocene to early Pliocene Sardine Formation is found in the southeastern part of the Stayton NE quadrangle. The Sardine Formation ranges from 5 to >30 m-thick on the Stayton NE quadrangle and unconformably overlies the older CRBG and Scotts Mills Formation. The Sardine Formation appears to generally mantle these older surfaces; no notable erosion or deep incisions into these pre-Sardine surfaces were found within the map area.

Exposures of the Sardine Formation on the Stayton NE quadrangle consists predominately of medial to distal volcaniclastic deposits produced by, and related to, western Cascade arc volcanism (Peck and others, 1964; Hampton, 1972; Priest and others, 1983; Hammond, 1989). Sardine volcaniclastic deposits consist of poorly indurated, fluvial pebble/cobble conglomerates, sandstones, and siltstones that are interbedded with the distal portions lahar run-out deposits. The upper surfaces of many of these beds display evidence of paleosol formation. The pebble and cobbles within the Sardine conglomerates appear to be predominately composed of Cascadian basalt, andesite, and dacite lithologies. Sardine volcaniclastic deposits are often moderately to severely weathered and typically develop deep soils.

Pyroclastic flows and lava flows are reported by Peck and others (1964), Hampton (1972), and Hammond (1989) to constitute a major component of the Sardine Formation in this region. However, no notable pyroclastic deposits were found within the map area and only a single, 10 m-thick, blocky andesite flow was found to be interbedded with volcaniclastic Sardine sediments on Waldo Hills Drive (sec. 12, T7S, R1W).

A middle to late Miocene age was originally assigned to the Sardine Formation by (Peck and others, 1964, p. 34-35) on the basis of fossil flora collected from this formation outside the map area. Peck and others (1964, p. 35) inferred that the upper portion of the Sardine Formation could be as young early Pliocene. Hampton (1972, p. 20-21) inferred that the upper age of the Sardine Formation must be early Pliocene based on interfingering relationships with the Troutdale Formation. No isotopic age determinations are reported for this formation.

Quaternary-Tertiary Sediments

Undifferentiated late Miocene to Pleistocene fluvial sediments unconformably overlie the CRBG in the central and northern Willamette Valley. Within the map area, this unit is only encountered in the subsurface; water well driller's logs describe it as consisting of unconsolidated to poorly indurated sands, silts, clays, and gravels. This unit is, in part, contemporaneous with the Sardine Formation and has been inferred to represent the southern extent of the Troutdale

Formation in the north-central Willamette Valley (Peck and others, 1964; Hampton, 1972). These sediments are thought to present deposits of an ancestral Willamette River and its tributaries.

Quaternary Alluvium

The Quaternary alluvium within the map area is informally subdivided into older (Qoal) and younger (Qal) deposits. The younger alluvial deposits are generally restricted to recent (Holocene) stream valleys. The older alluvial deposits (Pleistocene) consist of both local fluvial deposits and Cataclysmic ("Missoula or Spokane Floods") flood deposits. Fluvial deposits within the older alluvium consist of poorly to moderately indurated, fluvial basaltic conglomerates and sandstones that occur as minor terraces along the major stream valleys within the map area (e.g., Butte, Abiqua, Silver Creeks). These terrace deposits are typically less than 15 m-thick. In the map area, deposits produced by cataclysmic (Missoula) flood events generally mantle much of the topography below the 300 ft-elevation in, and immediately adjacent to the Willamette Valley. These deposits consist predominately of silt and fine sand (Hampton, 1972; McDowell and Roberts, 1987). Also associated with the cataclysmic flood deposits are angular to subrounded, pebble- to boulder-size rocks of exotic lithologies (e.g., granite, quartzite, gneiss). These "erratics" were transported to this area in icebergs carried by the flood waters (Allen and others, 1986).

Landslide Deposits

The only large landslide deposit was found on the Scotts Mills quadrangle along the southwest side of the Butte Creek Valley. Here hummocky topography consisting CRBG colluvium denotes the extent of the slide. The failure plane appears to have been the unconformity between the CRBG and Scotts Mills Formation.

STRUCTURAL GEOLOGY

General

The nature of flood basalts, such as the CRBG, makes them ideal for studying structural deformation. As fluids, although rather viscous, they flowed into and across the lowest parts of the topography so that their initial distributional patterns reveal the locations of topographic features at the time of their emplacement. Topographic highs greater than the flow thickness would not be covered, forming a margin of the flow or a hole in the distributional pattern. Topographic lows, such as a stream valley would be filled with an anonymously thick deposit. Since topography results from a combination of structural deformation, erosion, volcanism, and sedimentary deposition, the distributional patterns of the flood basalt flows, in combination with a knowledge of the confining rocks, provides valuable information about the geologic history to that time. Also, these flood basalt flows were very extensive, initially forming rather flat surfaces that provide reference datum planes for post-emplacement deformation. The detailed mapping of CRBG units in the Scotts Mills, Silverton, and Stayton NE quadrangles makes it possible to delineate the topography existing prior to the emplacement of CRBG flows and also the structural deformation occurring since the middle Miocene.

The distribution and deformation of the CRBG flows in this area reflect the more regional structural features. In general, the CRBG flows form a homocline that dips away from the axis of the Cascade Range and towards the Willamette Valley. The tabular CRBG unit plunges beneath the Willamette Valley sedimentary fill at about the 250 ft elevation and descends to a maximum depth of about 1300 ft below sea level in the center of the valley. Previous geologic studies have identified three major structural features within our map area, the northeast-trending Scotts Mills Anticline (Peck and others, 1964; Miller and Orr, 1984; Werner, 1991), the northeast-trending Waldo Hills range-front fault (Werner, 1991); and the Mount Angel Fault (Hampton, 1972; Beeson and others, 1985, 1989; Werner, 1991; Werner and others, 1992). Our mapping provides new data on these features as well as identifying many new structural features.

The structural pattern and history as determined from the mapping of these three quadrangles is subject to modification as we continue mapping other quadrangles in this area. We consider this to be a progress report in a much longer study. We are looking at a fairly small part the regional pattern and will need to study the larger area in order to better understand the nature and timing of deformation in this area.

Scotts Mills Anticline

Peck and others (1964) identified a northeast-trending anticline that they mapped extending from the vicinity of Victor Point School (sec. 36, T7S, R2W, Stayton NE quadrangle) to the confluence of Trout Creek and the Molalla River (T6S, R3E). This fold was defined on the basis of bedding attitudes measured in “marine tuff and sandstone” (Scotts Mills Formation) and the attitudes of flows and beds within the Little Butte Volcanics. Mapping by Orr and Miller (1984, 1986) and Miller and Orr (1984) redefined the location and extent of the southwestern portion of this fold. Orr and Miller (1984, 1986) mapping depicted this fold dying out east of the Stayton NE quadrangle (sec 33, T7S, R1E, Drake Crossing 7.5 minute quadrangle) and redefined the trace of the fold axis across the southeast corner of the Scotts Mills quadrangle (Miller and Orr, 1984). These changes were apparently based on 8 to 10 attitude measurements on beds within the Scotts Mills Formation (Orr and Miller, 1984, 1986; Miller and Orr, 1984). A cross-section through the Scotts Mills Anticline (see section A-A’, Miller and Orr, 1984) depicts this feature as a relatively indistinct, low amplitude fold.

In our mapping of the Scotts Mills quadrangle, we could not find compelling field evidence for the existence of the Scotts Mills Anticline. Attitude data measured on bedding planes within the Scotts Mills Formation do not indicate the presence of a northeast-trending anticlinal fold as depicted by either Miller and Orr (1984) or Peck and others (1964). Distribution and apparent attitude of the CRBG units do not indicate the presence of a northeast-trending anticlinal fold. Instead, our mapping suggests that deformation observed in the Scotts Mills Formation is likely related to block faulting (both pre- and post-CRBG emplacement). "Windows" through the CRBG into older marine sediments of the Scotts Mills Formation and Cascadian volcanic rocks of the Little Butte Volcanics are common in this area indicating that they were topographic highs immediately prior to, and during, the emplacement of CRBG flows. This exposure pattern of pre-CRBG rocks indicates that the paleotopography was irregular, with enough topographic relief to contain up to 180 m of CRBG flows and still not be totally covered by CRBG flows. We think that a large amount of the pre-CRBG topographic relief was produced by structural deformation (faulting) and augmented by differential erosion along weak rock zones.

Waldo Hills Range-Front Fault

Werner (1991) inferred the presence of a major northeast-trending fault, the Waldo Hills range-front fault, that defined the margin of the Willamette Basin along the Waldo and Silverton Hills. His evidence for this major fault was the linearity of the range front, distribution of geologic units (Hampton, 1972), and interpretation of the geology and elevation of units in water wells across this feature. Although northeast-trending faults are fairly common in the CRBG of this area, the northeast-trending topographic lineament marking the edge of the valley on the three quadrangles we mapped is probably not a major fault line. Surface mapping of CRBG flows and interpretation of available water well driller's logs suggest that the CRBG dips gently into the valley rather than being abruptly down-faulted at this transition.

Northwest-Trending Faults

The predominant structural features mapped in the CRBG in these quadrangles are northwest-trending faults and the associated cross-faults that typically have either north-south or northeast trends. We believe that many of the smaller cross-faults that we have mapped in the CRBG could be largely confined to the CRBG "slab", the product of brittle deformation in a thin, rigid, slab (CRBG) over a much less competent material (e.g., sedimentary rocks of the Scotts Mills Formation). Only the more continuous faults would project to great crustal depths.

The northwest-trending faults are the most continuous structures identified within the map area, with two being of particular significance - the Mount Angel fault zone (part of the Gales Creek - Mount Angel structural zone) and the Waldo Hills structural zone.

Mount Angel Fault Zone

The Mount Angel fault was originally identified and mapped by Hampton (1972) and subsequently considered as part of the regional-scale, northwest-trending Gales Creek- Mt. Angel structural zone (Beeson and others, 1985, 1989). Werner (1991) conducted the first detailed subsurface analysis of this feature in the Mount Angel - Woodburn area based on commercially available seismic-reflection data and water well data. His work confirmed that the Mount Angel fault extended northwest of the town of Mount Angel and consists of multiple fault strands that form a positive “flower structure” and that these faults offset Pliocene fluvial sediments. Werner’s (1991) analysis also found that the Mount Angel fault (zone) had a complex history, with deformation related to dextral strike-slip and dip-slip movement. Evaluation of focal mechanism solutions for recent earthquakes along the Mount Angel fault also favors a dextral strike-slip solution (Werner and others, 1992). The damaging M=5.6 Scotts Mills earthquake of 1993 was centered about 3 km east of Scotts Mills along the boundary of the map area. Focal mechanisms indicate oblique dextral-thrust motion or a northeast dipping fault plane inferred to be the projection of the Mt. Angel fault (Madin and others, 1993).

Mapping of Mount Angel and interpretation of water well driller’s logs from this area provide some additional insights into the structural geology of this fault zone. Our mapping (see Silverton quadrangle and cross-section) indicates that the structural geology along this portion of the Gales Creek-Mount Angel structural zone is more complex than previously realized (Werner and others, 1992). Mount Angel fault, as depicted by Werner (1991) and Werner and others (1992) does extend northwest from the Abiqua Creek valley along the southwest side of Mount Angel. The maximum apparent vertical stratigraphic offset on this fault occurs in the Mount Angel area (>200 m) but decreases to < 30 m in the Abiqua Creek valley with an opposite sense of throw (down to the northeast). This decrease in apparent offset and change in throw on the Mount Angel fault in the Abiqua Creek valley (see Scotts Mills quadrangle) is probably related to the numerous north-south- and northeast-trending faults (splays) that intersect this fault zone; deformation has been distributed to these splays significantly decreasing the magnitude of offset on the Mount Angel fault. These cross-trending faults, like most faults within the CRBG, do not simply consist of a single fault plane, but instead seem to consist of a series of parallel (anastomosing) faults. These faults collectively define the fault zone, which can vary in overall width (from tens to hundreds of meters). Depending on the intensity of deformation, CRBG flows between these fault strands can range from nearly intact (intraflow structures readily recognizable and undeformed) to high disrupted (shatter breccia). On Davis Creek (Scotts Mills quadrangle, NW 1/4 sec. 47, T6S, R1E) quarry operations in the Winter Water flows (Grande Ronde Basalt) provide good exposures of fault strands related to both north- south- and northwest-trending fault zones. The apparent vertical stratigraphic offset on these exposed fault strands is minor (< 3 to 5 m), with the width of the individual faults (shatter breccia and gouge) typically less than 0.5 m. The fault planes commonly display sets of both subvertical and subhorizontal slickenside striae indicating that both dip-slip and strike-slip movement(s) have occurred on these faults.

No exposures of the Mount Angel fault are found within the map area. However along the southeast projection of the Mount Angel fault in upper Abiqua Creek (just above Abiqua Falls), we have found an exposure of this fault zone (shatter breccia/gouge) that contains several near-vertical slip surfaces on which subhorizontal slickenside striae are found.

The trace of the Mount Angel fault is inferred to be along the southwest side of Mount Angel (Hampton, 1972; Beeson and others, 1989; Werner, 1991). Our mapping indicates that Mount Angel is a fault-bounded block (horst) that dips to the northeast and plunges off along its long axis to both the northwest and southeast. The Mount Angel horst is further segmented by northeast-trending cross-faults (see Silverton quadrangle).

An apparently similar structure occurs along this same trend approximately 1.5 km northwest of the Mount Angel horst. This uplifted block is separated from the Mount Angel horst by a fault-bounded low (graben) where the City of Mount Angel is located (see Silverton quadrangle). This structure is bounded on the southwest side by the Mount Angel fault and on its southeast end by a northeast-trending cross-fault. No data were available to establish whether faults were present along the northeast and northwest sides of this structure. Based on data from water well logs, the apparent vertical stratigraphic offset on the CRBG across the Mount Angel fault here is > 200 m. This offset is of the same magnitude as that at the Mount Angel horst, but the current topographic expression on this structure is minimal. South of Mount Angel, the Mount Angel fault and another parallel fault form a northwest-trending graben (see Silverton quadrangle and cross-section). Subsurface data indicate that this graben extends northwest from section 50 to at least Highway 214; water wells in Walker Ditch (south and west of the City of Mount Angel) suggest that this structure may continue northwestward to the Pudding River. The geomorphic expression of this feature and data from water well driller's logs suggest that Abiqua Creek once followed this feature to its confluence with the Pudding River northwest of the present-day city of Mount Angel. Abiqua Creek now turns west at section 50 and has abandon this former channel. Similar westward turn is exhibited by Silver Creek. The reason for these drainage changes are not known, but could be caused by either tectonic events (e.g., deformation along faults) or the cataclysmic Missoula Floods.

CRBG distributional patterns indicate that the active Mount Angel fault existed during Middle Miocene time. The Mt. Angel fault (Gales Creek-Mount Angel structural zone) is one of the major northwest-trending structural zones that acted as a topographic barrier to the advance of certain CRBG flows. Specifically, only the uppermost Silver Falls flows appears to have advanced past this feature, while the lower, abundantly phyric Silver Falls flow was stopped by this structure. The time interval between the emplacement of the last Grande Ronde flow (Sentinel Bluffs Member) and the first Frenchman Springs flow (abundantly phyric Silver Falls flow) is probably the longest such interval, providing enough time for continuing deformation along this structural zone to create a topographic obstacle for the first Silver Falls flow. The termination of this flow here indicates that this northwest-trending fault zone was active at least by 15.5 m.y. ago.

Waldo Hills Structural Zone

Prior to this study, no northwest-trending faults or folds had been mapped in the southwest portion of the Stayton NE quadrangle (Orr and Miller, 1984; Werner, 1991). The series of aligned northwest-trending hills in the southwest corner of the Stayton NE quadrangle was mapped by Orr and Miller (1984) as erosional remnants of the Sardine Formation. Our mapping has found that these hills are CRBG-cored anticlinal folds that are related to a series of through-going northwest-trending faults that we term the Waldo Hills structural zone.

The Waldo Hills structural zone consists of a series of parallel, northwest-trending faults and elongate domical folds that cross the southwest corner of the Stayton NE quadrangle. This structural zone as been traced for more than 20 km across portions of the Stayton, Stayton NE, and Salem East 7.5 minute quadrangles, but it total length is yet to be determined. The width of this structural zone is variable, ranging from 1 to >2.5 km. The Waldo Hills structural zone is parallel to the Gales Creek-Mount Angel structural zone (Mount Angel fault zone) and the Portland Hills-Clackamas River structural zone (Fig. 3); the dominant sense of movement on each of these zones is probably dextral strike-slip movement (Beeson and others, 1989; Werner, 1991; Blakely and others, 1995).

The folds associated with this feature are typically elongate, domical folds with their long axis either parallel, or subparallel, to the overall trend of the Waldo Hills structural zone. The northeast limbs of these anticlines are steeper than their southwestern limbs, producing a pronounced asymmetric profile. Two of these anticlines (sec. 78, T8S, R1W) have a northwest-trending fault along the base of their northeast limbs. The overall geometry of the elongate, domical folds associated with the Waldo Hills structural zone is very similar to domical folds associated with northwest-trending, dextral wrench fault zones in the western Columbia Plateau region (Anderson, 1987). Another similarity is that several of the northwest-trending faults within the Waldo Hills structural zone display reversals of apparent dip-slip separation (scissoring) along their strike. Together, these features strongly suggest that the Waldo Hills structural zone represents a dextral wrench fault zone.

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Figure 1. Map showing the location of the Silverton, Scotts Mills, and Stayton NE 7.5 minute quadrangle.

Figure 2. Generalized sketch map showing the distribution of the Cascade volcanic arc and Columbia River Basalt Group in relation to selected regional-scale tectonic features (modified from *Beeson and Tolan, 1990*). The westward-dipping Palouse Slope directed erupting CRBG lava towards the Pasco Basin and Columbia Trans-Arc Lowland. The Columbia Trans-Arc Lowland was a low that transected the mid to late Miocene Cascade Range and allowed CRBG flows to enter western Oregon and Washington. In western Oregon, CRBG flows encountered two major northwest-trending dextral wrench fault systems, the Portland Hills - Clackamas River structural zone (PHCR) and the Gales Creek - Mount Angel structural zone (GCMA). P = Portland, D = The Dalles, H = Mt. Hood, A= Mt. Adams, SH = Mt. St. Helens.

Figure 3. Sketch map showing the locations of major CRBG intracanyon flow pathways western Oregon and Washington. Modified from Beeson and Tolan (1996).

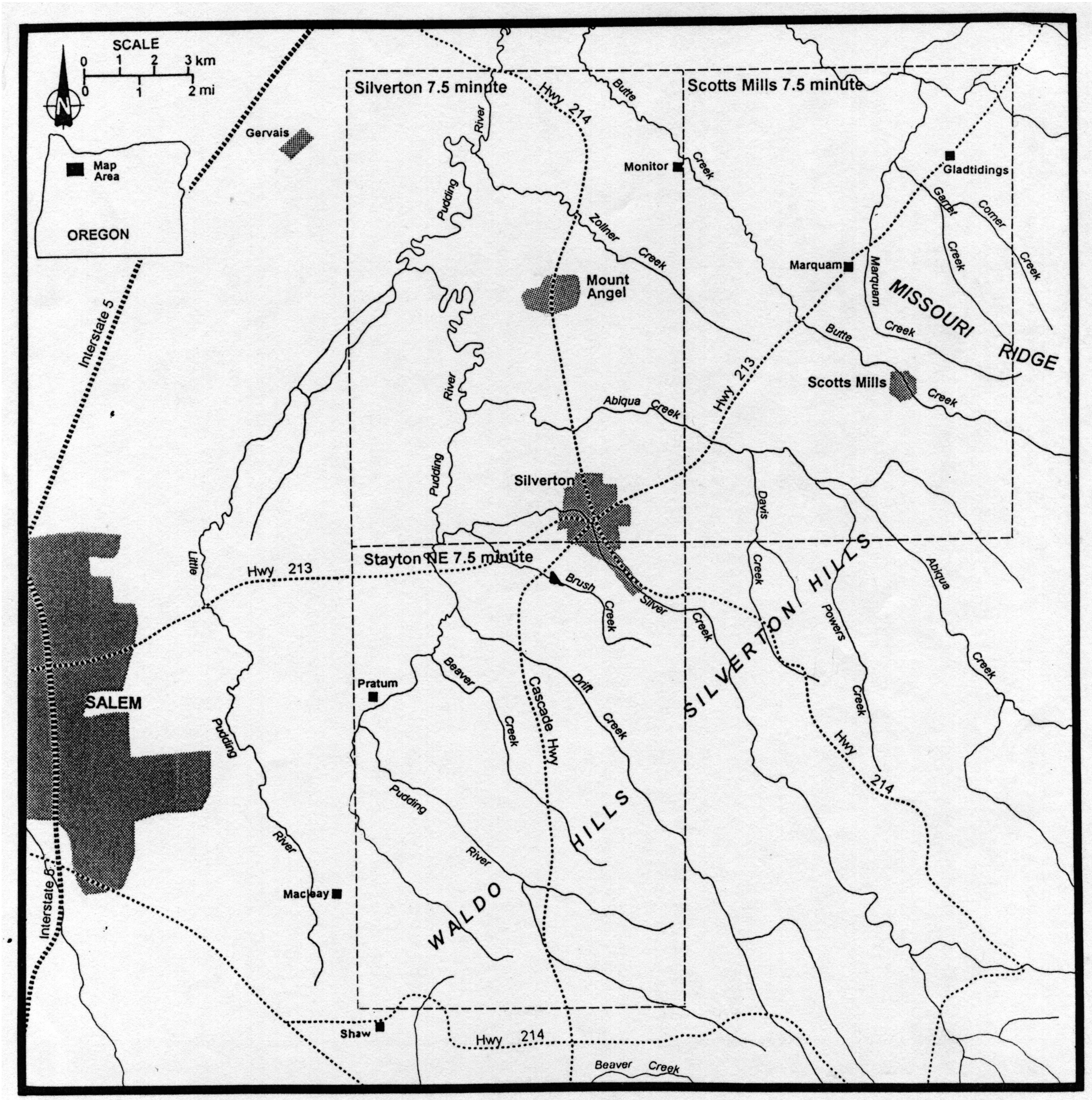
Figure 4. Stratigraphic nomenclature, age, and magnetic polarity for Columbia River Basalt Group units (from Tolan and others, 1989). Black arrows indicate units that are present within the Silverton, Scotts Mills, and Stayton NE 7.5 minute quadrangles. N= normal magnetic polarity, R = reversed magnetic polarity, T = transitional magnetic polarity, E = excursional magnetic polarity.

Figure 5. Maps showing the regional extent of Columbia River Basalt Group unit, Scotts Mills, and Stayton NE 7.5 minute quadrangles. A = basalt of Sand Hollow, Frenchman Springs Member, Wanapum Basalt; B = basalt Silver Falls, Frenchman Springs Member, Wanapum Basalt; C = Sentinel Bluffs Member, Grande Ronde Basalt; D= Winter Water member, Grande Ronde Basalt; E = Ortley Member, Grande Ronde Basalt; F= Umtanum Member, Grande Ronde Basalt. Note that Ortley and Umtanum Members are shown as an undifferentiated unit (TgN2l) on the geologic map and cross-section. Distribution maps from Tolan and others (1989) and Reidel and others (1989).

Table 1. Chemical composition of Little Butte Volcanics and Columbia River Baslat Group units — Scotts Mills, Silverton, and Stayton NE 7.5 minute quadrangles.

Sheet 1. Geologic map of the Silverton and Scotts Mills 7.5 minute quadranges, Northwest Oregon.

Sheet 2. Geologic map of the Stayton NE 7.5 minute quadrangle, Northwest Oregeon.



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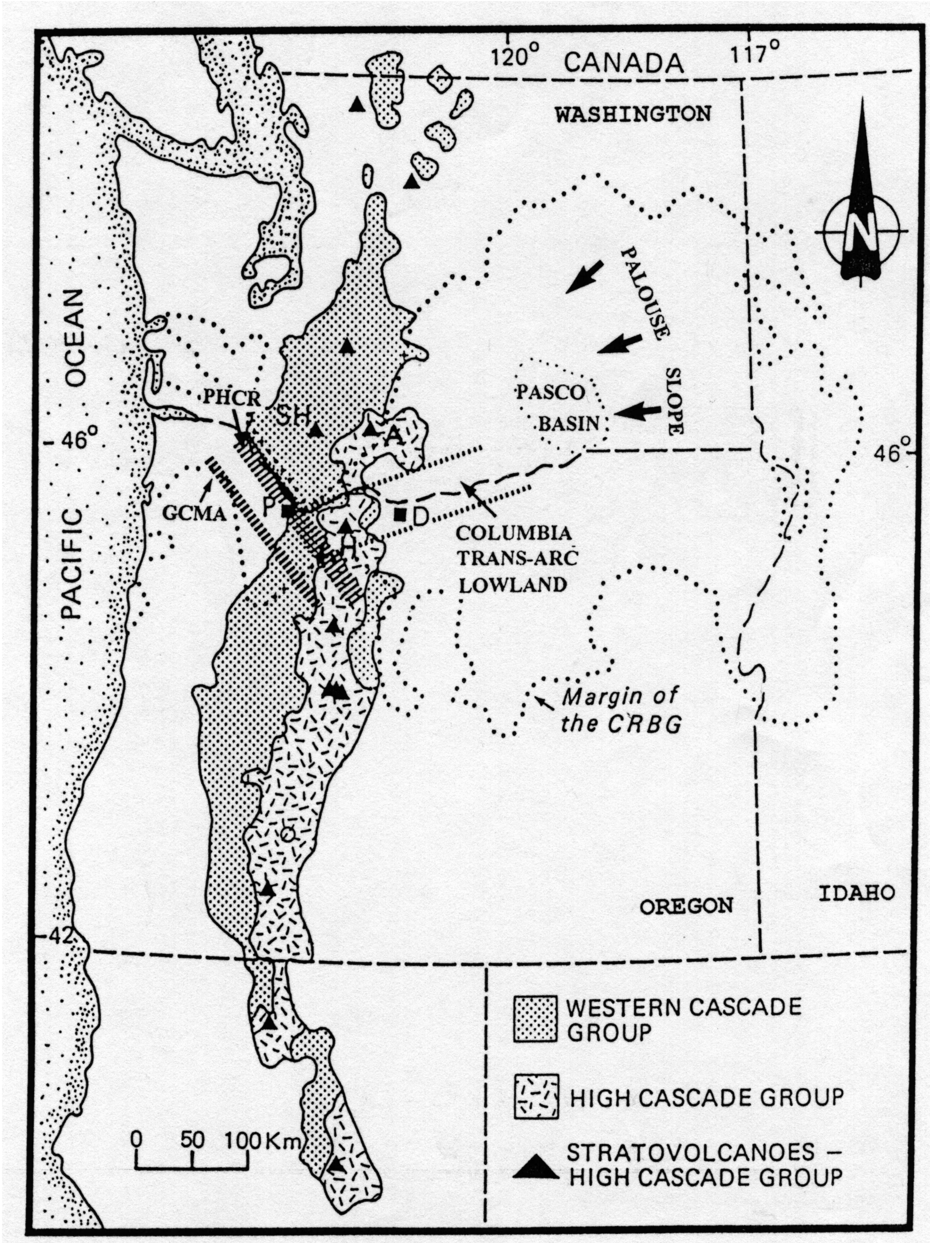

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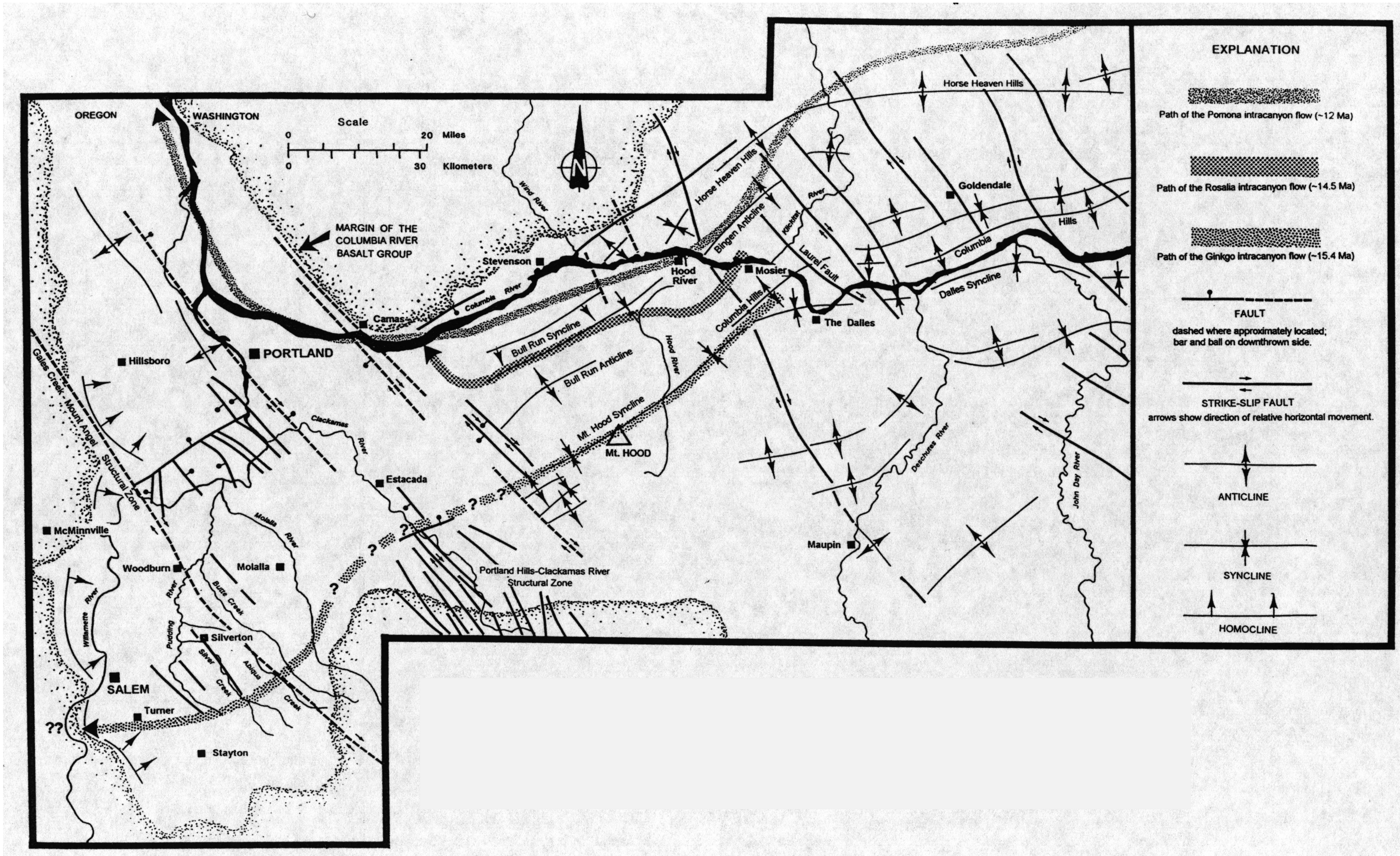


Figure 3. Sketch map showing the locations of major CRBG intracanyon flow pathways western Oregon and Washington. Modified from Beeson and Tolan (1996).

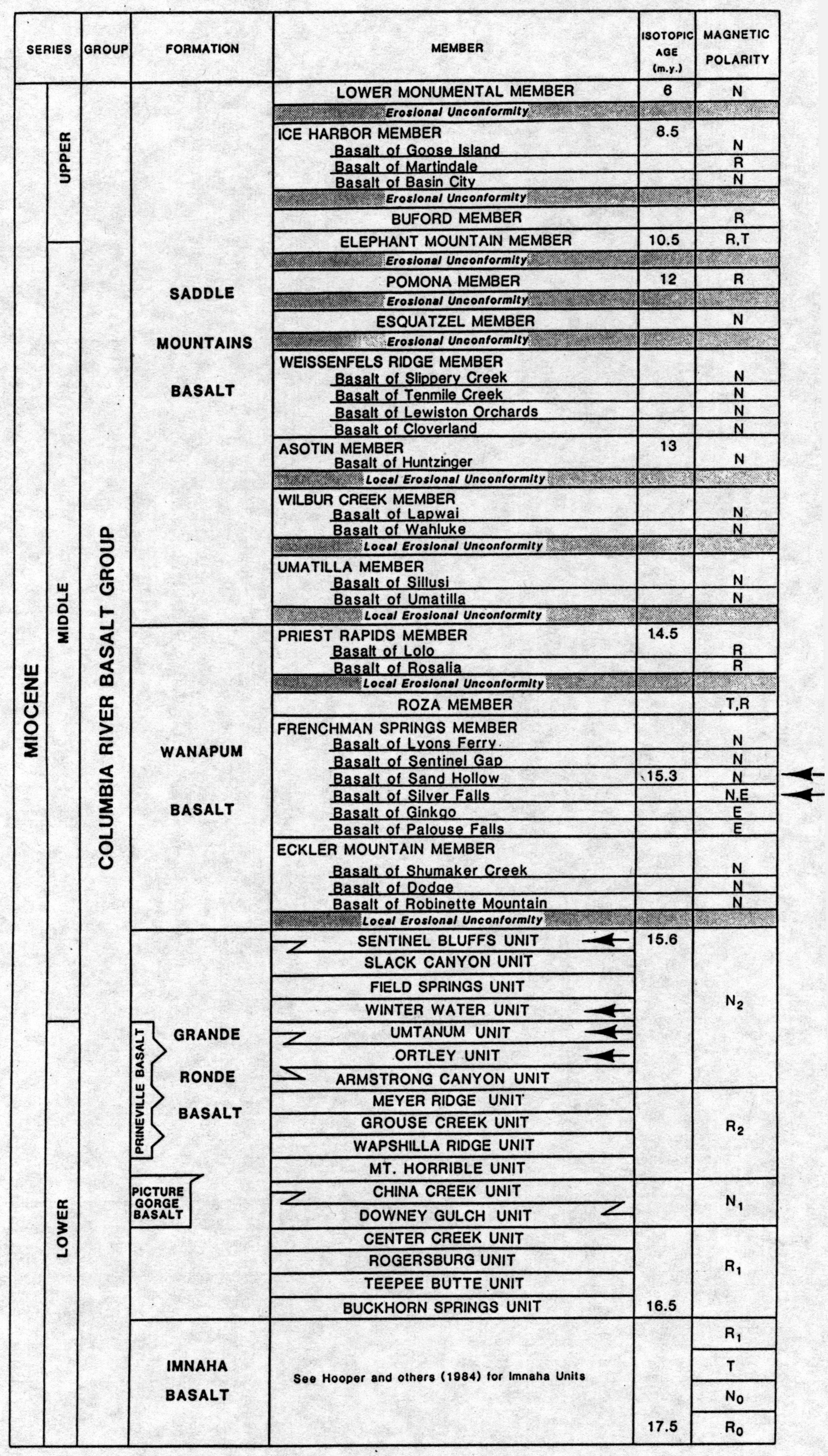
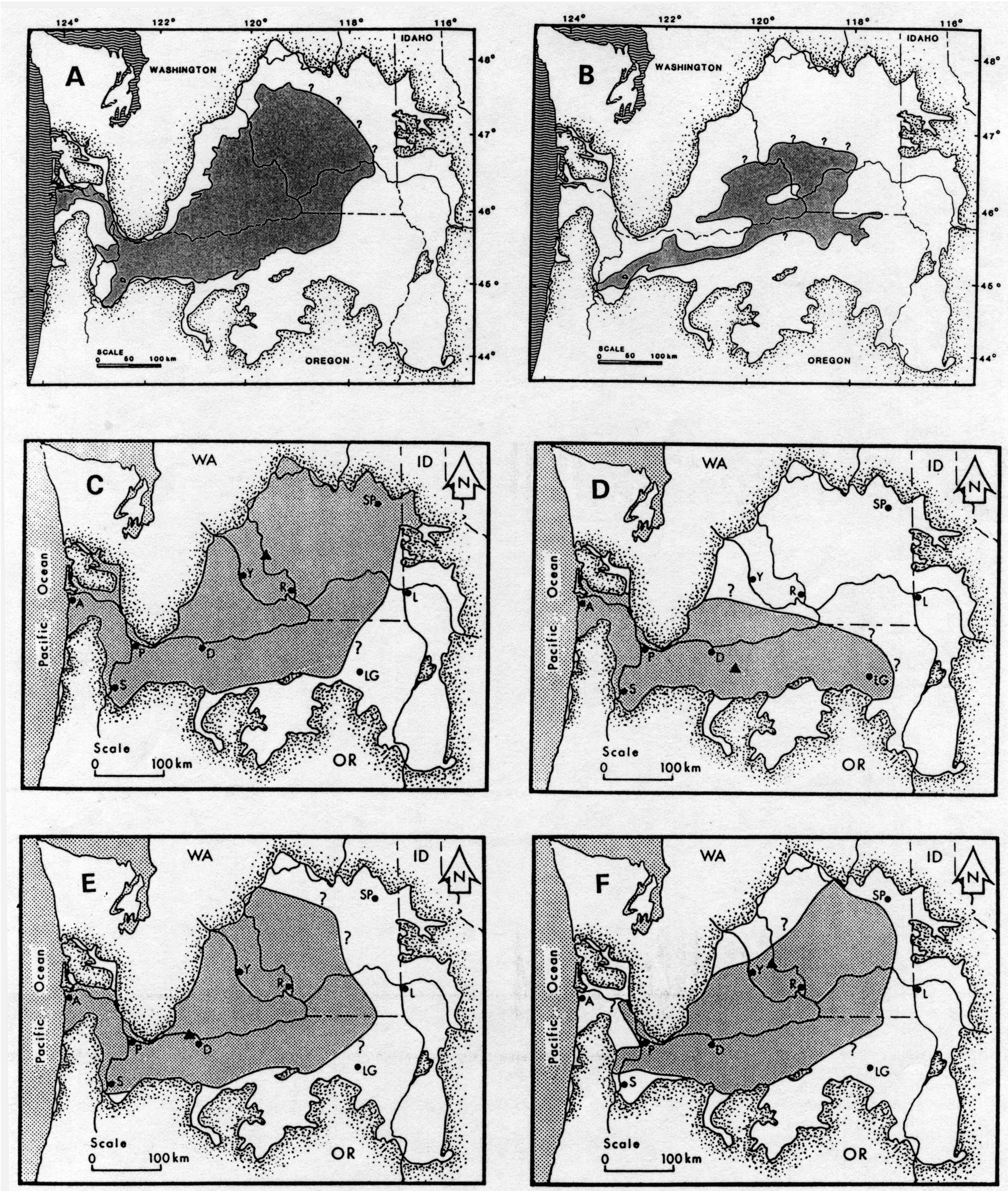


Figure 4. Stratigraphic nomenclature, age, and magnetic polarity for Columbia River Basalt Group units (from Tolan and others, 1989). Black arrows indicate units that are present within the Silverton, Scotts Mills, and Stayton NE 7.5 minute quadrangles. N= normal magnetic polarity, R = reversed magnetic polarity, T= transitional magnetic polarity, E = excursional magnetic polarity.



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	LITTLE BUTTE VOLCANICS			COLUMBIA RIVER BASALT GROUP				
				Grande Ronde Basalt			Frenchman Springs Member	
				Umtanum Member	Winter Water Member	Sentinel Bluffs Member	Basalt of Silver Falls	Basalt of Sand Hollow
	basalt	andesite	andesite					
					mean ± 1σ	mean ± 1σ	mean ± 1σ	mean ± 1σ
SiO_2	50.83	58.5	61.66	56.7	57.52 ± 0.47	54.23 ± 0.79	51.1 ± 0.37	51.99 ± 0.34
Al_20_3	16.01	18.62	16.72	13.7	13.89 ± 0.24	14.21 ± 0.31	13.45 ± 0.47	13.56 ± 0.03
TiO_2	0.83	0.95	1.08	2.12	2.17 ± 0.03	1.97 ± 0.12	3.19 ± 0.08	2.85 ± 0.02
FeO^*	8.48	6.61	7.1	11.63	10.74 ± 0.72	12.09 ± 1.24	15.26 ± 0.92	13.81 ± 0.27
MnO	0.17	0.13	0.13	0.22	0.18 ± 0.01	0.21 ± 0.03	0.28 ± 0.06	0.23 ± 0.01
CaO	11.36	8.03	5.29	7.15	6.88 ± 0.02	8.67 ± 0.11	8.18 ± 0.11	8.39 ± 0.04
MgO	9.87	2.66	2	3.32	3.08 ± 0.02	4.01 ± 0.08	3.72 ± 0.77	4.46 ± 0.1
K_20	0.44	0.59	1.31	1.63	1.92 ± 0.13	1.24 ± 0.05	1.32 ± 0.09	1.3 ± 0.05
Na_20	1.84	3.69	4.45	3.15	3.24 ± 0.08	3.03 ± 0.06	2.88 ± 0.13	2.84 ± 0.11
P_20_5	0.17	0.22	0.26	0.38	0.38 ± 0.01	0.34 ± 0.01	0.62 ± 0.03	0.57 ± 0.01
Trace Elements (ppm)								
Ni	121	12	15	0	0 ± 0	7 ± 4	3 ± 3	13 ± 4
Cr	435	31	13	15	12 ± 1	42 ± 6	31 ± 1	52 ± 3
Sc	34	23	24	29	41 ± 2	38 ± 2	33 ± 2	40 ± 2
V	241	102	121	325	324 ± 11	320 ± 1	433 ± 17	417 ± 9
Ba	89	212	306	701	715 ± 79	502 ± 23	662 ± 84	494 ± 19
Rb	5	32	30	47	52 ± 2	29 ± 1	31 ± 2	32 ± 2
Sr	370	319	285	323	334 ± 2	317 ± 12	321 ± 20	315 ± 1
Zr	96	158	191	185	187 ± 2	162 ± 6	178 ± 7	177 ± 1
Y	17	28	30	39	40 ± 2	35 ± 2	42 ± 2	43 ± 1
Nb	6.5	12	16.7	13.9	15.1 ± 0.3	12.8 ± 1.6	15.1 ± 0.4	15.8 ± 0.8
Ga	15	20	20	23	23 ± 1	21 ± 1	23 ± 2	21 ± 2
Cu	116	75	98	2	1 ± 1	25 ± 2	17 ± 6	18 ± 2
Zn	75	71	81	129	133 ± 1	116 ± 8	145 ± 6	129 ± 2
Pb	3	3	7	12	8 ± 1	2 ± 1	5 ± 2	8 ± 1
La'	6	20	26	36	34 ± 1	17 ± 5	27 ± 2	19 ± 14
Ce	9	34	48	47	48 ± 1	45 ± 7	40 ± 8	64 ± 14
Th	2	2	5	8	8 ± 1	3 ± 2	7 ± 1	3 ± 1
No. Sample	1	1	1	1	2	3	4	3

* Total Fe is expressed as FeO. No. Samples - denotes number of analyses used to compute mean and one standard deviation (1 sigma). Major elements are normalized on a volatile-free basis. Allanalyses performed by the GeoAnalytic Laboratory at Washington State University.

Table 1. Chemical composition of Little Butte Volcanics and Columbia River Basalt Group units — Scotts Mills, Silverton, and Stayton NE 7.5 minute quadrangles.